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U. S. DEPARTMENT OF COMMERCE

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COAST AND GEODETIC SURVEY

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FIRST-ORDER LEVELING

Leveling is the operation of determining differences of elevation between any two points on the surface of the earth. There are few surveying or civil-engineering operations in which leveling does not occur in some form. While for many purposes only the relative elevations of points are required, it is desirable for the proper coordination and comparison of leveling results that all elevations be referred to a common datum or surface of reference. In the network of leveling which covers the United States, the elevations are expressed in meters and feet above the mean level of the sea. The mean

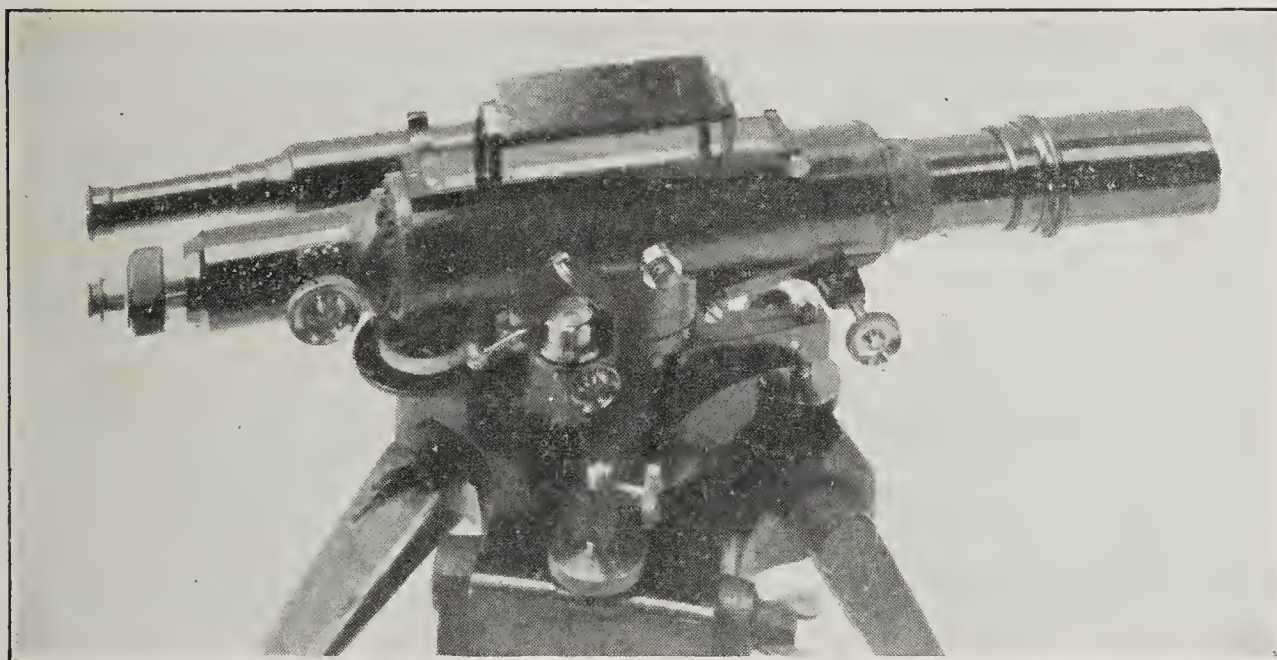


FIGURE 1.—FISCHER FIRST-ORDER LEVEL.

This instrument has an extremely sensitive level bubble and is so constructed that the observer may see the bubble with one eye and read the rod with the other without moving about the instrument.

level of the sea is assumed to be at the same elevation on the open coasts of the Atlantic and Pacific Oceans and the Gulf of Mexico, and it provides a datum easily established and accessible at many widely separated points.

The principal method now in use in the Coast and Geodetic Survey for the determination of elevations is first-order leveling. This is the most accurate method known and differs from ordinary leveling only in the sensitiveness of the instruments used, the care with which the observations are made, and the refinement of the computations.

INSTRUMENTS

The instrument used in first-order leveling (see fig. 1) consists, essentially, of a telescope carrying a delicate spirit level mounted in such a manner on a portable tripod that it may be quickly and readily placed in a horizontal position.

Various types of instruments have been used for first-order leveling, some of them being nearly like the Y level used extensively by engineers on construction work, and others differing widely from it. The principal characteristics which distinguish the form of first-order level now in use in the Coast and Geodetic Survey are the irreversibility of the telescope and level; the absence of wyes; the rigid fastening of the level vial to the telescope, and its juxtaposition to the latter, in the barrel of which it is counter-sunk; the use in the construction of the telescope and adjacent parts of a metal known as invar which has a very small coefficient of expansion; the protection of the level vial and the middle part of telescope from sudden and unequal changes of temperature by incasing them in an outer tube; and an arrangement by which, without any change of the observer's position, the level bubble can be clearly seen by his left eye at nearly the same instant in which the distant rod is observed through the telescope by his right eye.

RODS

The readings are made upon a graduated metal strip of invar. The strip, which is about 1 inch wide, fits loosely in a groove of a flat wooden rod about 10 feet long, and it is free to move upward for temperature changes, being fastened rigidly only at the bottom of the rod. The bottom of the rod is made of metal and terminates in a flat base of hardened steel about 1 inch in diameter. When leveling along a railroad, the top of a spike, which serves to hold the rail in place, is used as the rod support; off the railroad the rod is supported on the top of a steel pin driven in the ground.

For a complete description of the instrument, the rods, and the method of graduating the rods, see Coast and Geodetic Survey Special Publication No. 129, *Geodetic Level and Rod*, revised (1935) edition.

FIELD PROCEDURE

The first-order leveling of the Coast and Geodetic Survey is run along railroads and improved highways. Automobile trucks are used for transporting the leveling party to and from the working grounds, but during the actual leveling the party walks.

Graduated rods are held at two points, the instrument being placed midway between them. The telescope is sighted first on one rod and then on the other. The difference of the readings of the rods is the difference of height between the two points. The length of sight is usually short and should not exceed 165 yards, under most favorable conditions. By repeating the operation at successive stations the difference of elevation of widely separated points is determined.

A line of levels is broken up into sections about a mile in length, and each section is always run twice in opposite directions. In case of disagreement of the results beyond prescribed limits, one

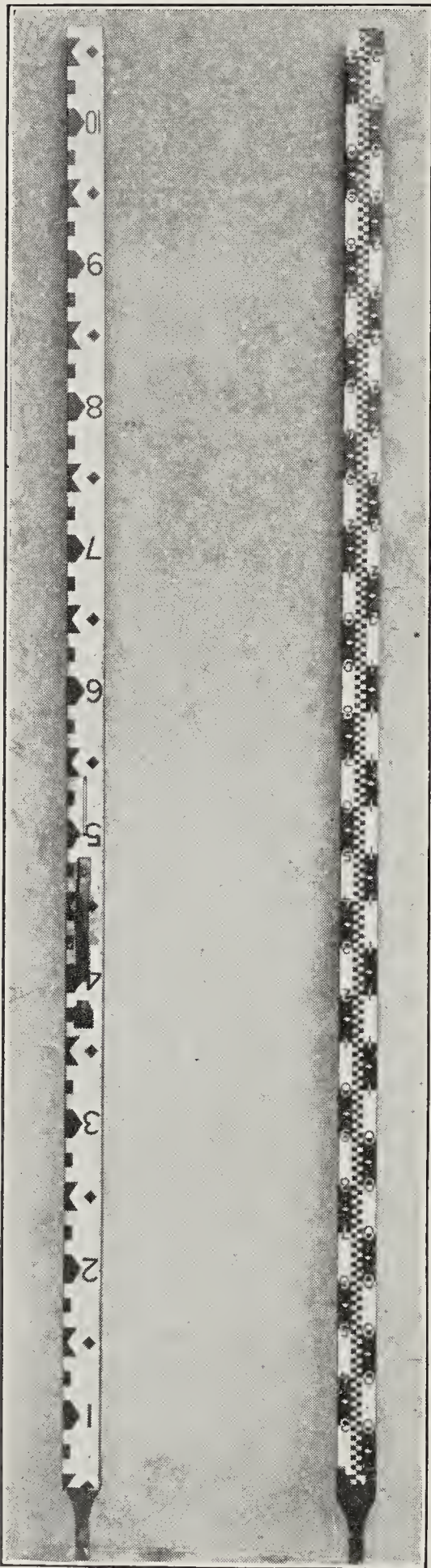


FIGURE 2.—FIRST-ORDER LEVEL RODS.

Both the face and back of the rods are shown. Three wires are read on the face of the rod and the middle one of the three is read on the back as a rough check.



FIGURE 3.—A FIRST-ORDER LEVEL PARTY IN ACTION.

The umbrella is to protect the instrument from the heat of the sun rather than for the comfort of the observer. One of the two rodmen does not appear in the picture.

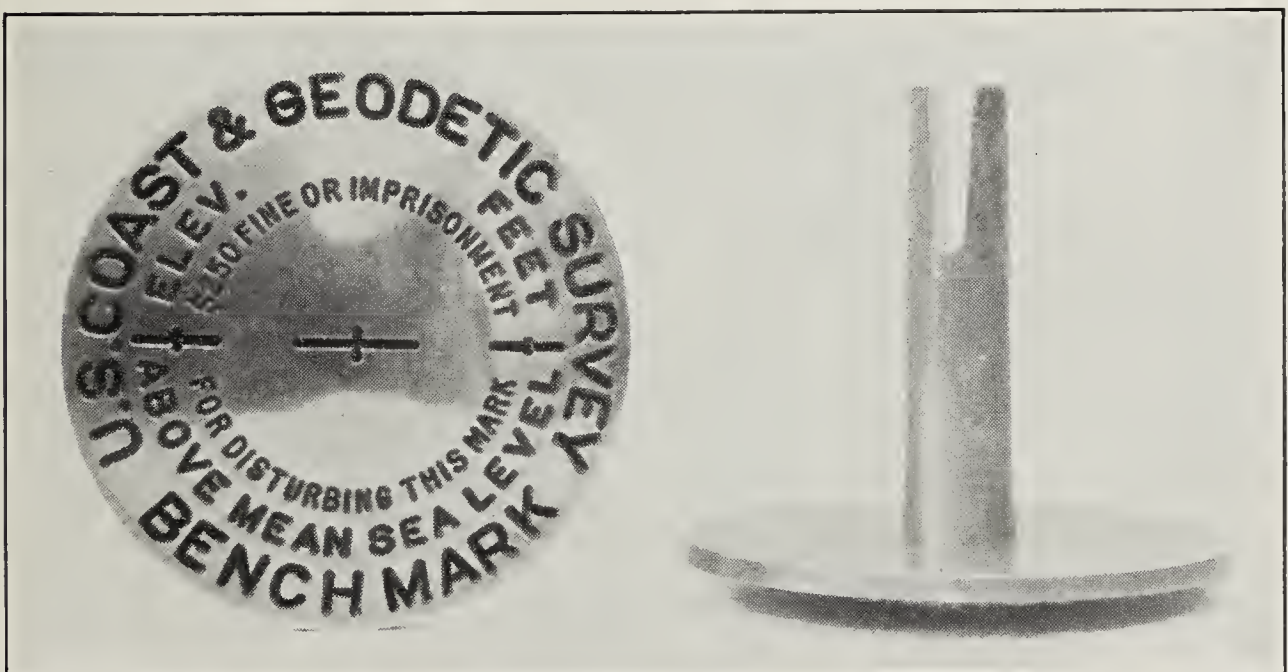


FIGURE 4.—A STANDARD BENCH-MARK TABLET.

This tablet is set solidly in masonry structures, rock outcrops, boulders, or concrete posts so that only the inscribed disk is visible.

or more additional runnings are made. Permanent points called bench marks (see fig. 4) are established at short intervals for the use of surveyors and engineers.

ACCURACY

For the leveling done since 1899 the maximum discrepancy allowed between two measurements on a section 1.6 kilometers (1 mile) long is 5 millimeters, or one-fifth of an inch. For sections of other lengths the discrepancy allowed is proportional to the square root of the length.

A much more severe test of the accuracy of the leveling is obtained from the closures of large circuits, 50, 100, or 1,000 miles in circumference. When elevations are carried from one point continuously in one direction around the circuit, the computed elevation for the starting point on closing the circuit should agree with that assumed for it at the start if there are no errors in the leveling.

In the network of first-order leveling which now covers the United States there are approximately 500 such circuits. The lines are so interlaced that each line usually forms a part of two circuits. The greatest error indicated by the circuit closures in any line of the whole system, involving about 100,000 miles of leveling executed by the Coast and Geodetic Survey, the Corps of Engineers (U. S. Army), and other organizations, is 2 millimeters per kilometer, or about one-eighth of an inch per mile, while the average error is 0.3 millimeter per kilometer, or about one-fiftieth of an inch per mile. The leveling done in recent years by the Coast and Geodetic Survey has an average closing error about 0.2 millimeter per kilometer.

EXTENT

Since the adoption of the present instrument and methods the Coast and Geodetic Survey has completed over 85,000 miles of first-order leveling. The average rate of progress of this leveling has been about 75 miles per month per party of six men, each mile being leveled at least twice, once in a forward and once in a backward direction. During the month in which the most rapid leveling was done, 165 miles of line were completed by a single party. The cost of this recent leveling has been from \$7 to \$16.50 per mile of progress, leveled in both directions.

First-order leveling will eventually cover the whole United States with a network of lines spaced at intervals of approximately 100 miles. Within the areas formed by these lines of first-order leveling, second-order levels will be run at intervals of 50 and 25 miles, approximately. At present there is very little first-order leveling left to complete the above program and the second-order leveling will be finished by the summer of 1935 insofar as available routes can be found along which the line of levels can be run economically. In some of the high mountain regions it is impossible at the present time to complete the net to the 50- and 25-mile spacings for lack of railroads or highways along which the lines of levels can be extended.

Second-order leveling is run with the same instrumental equipment and under the same general instructions as first-order leveling, the only difference being that the second-order leveling is run once and not leveled in both directions as is the case with first-order leveling. By the middle of the summer of 1935, approximately one-quarter of a million miles of first- and second-order leveling will have been run and included in the fundamental leveling net of the United States.

As the first- and second-order leveling to reduce the fundamental net to the 25-mile spacing is practically completed, the work of further subdividing the net is now in progress and will require probably more than a quarter million miles of additional lines of levels, to furnish the vertical control for the topographic mapping of the country.